APPENDIX D

METHODOLOGY FOR COMPUTING MARKET AND WELFARE ADJUSTMENTS

D.1 METHODOLOGY FOR COMPUTING SUPPLY EFFECTS

For the purposes of modeling the regulatory effects in each market, products are separated into four categories, based on their producers' response to the regulation:

- products slated for withdrawal,
- products on which exceedance fees are paid,
- products slated for reformulation, and
- products unconstrained by the regulation.

The baseline (preregulatory) quantities from these groups are denoted as follows: Q^X, Q^F, Q^R, and Q^U for groups 1, 2, 3, and 4, respectively. Total baseline market output equals the sum of the four components:

$$Q = Q^X + Q^F + Q^R + Q^U. \qquad \text{(D.1)}$$

Figure D-1 depicts the aggregation of these subgroups into a market supply function. The regulation causes a shift in the aggregate supply function depicted in Figure D-1 as a result of two phenomena: an inward supply shift due to eliminating Group 1 through product withdrawals (e.g., the shift from S^0 to S^1), and an upward supply shift due to imposing per-unit fees on the products from Group 2 (the shift from S^1 to $S^{1'}$). There is no supply shift emanating from

Figure D-1. Single market effects of VOC content regulation.

Group 3 because the reformulation is assumed not to affect marginal production costs, and there is no shift from Group 4 because the unconstrained products experience no regulation-induced change in their cost structure. So the full regulation-related shift is from S^0 to $S^{1'}$, which leads to a new market equilibrium. At the new equilibrium, price rises to P′ and quantity falls to Q′.[a]

[a]This graphical analysis demonstrates that the post-regulatory market effects are uncertain if the analysis were to consider the possibility that the reformulation process changes the marginal cost of producing the coating as a result of changes in material or labor costs, for example. This empirical issue can be resolved given sufficient data on the effect of VOC content on production costs for all affected products. Unfortunately, these data were not available for this study, so the appropriate empirical analysis could not be conducted to draw such conclusions.

D.2 DEMAND EFFECTS

Figure D-1 depicts a partial equilibrium view of the short-run effect of imposing content limits in one market. One must also consider the role of substitute products in determining the equilibrium adjustments, which suggests a multimarket perspective. Figure D-2 depicts the markets for two products (A and B) that are demand substitutes. The price of product B factors into product A's demand function and vice versa:

$$D_A = D_A(P_A, P_B) \quad (D.2)$$

$$D_B = D_B(P_B, P_A). \quad (D.3)$$

Given that A and B are substitutes implies

$$*D_A / *P_B > 0 \quad (D.4)$$

$$*D_B / *P_A > 0 \ . \quad (D.5)$$

Suppose the supply of A is affected by the content limits in the manner described above, but that the supply of B is unaffected. This initiates a supply shift in market A from S_A^0 to S_A^R. Holding the initial demand function constant, this shift would generate an equilibrium quantity of Q_A" and price of PA". However, the associated price increase in market A induces an outward shift in the demand for product B, which raises the price of product B. Likewise, the increase in B's price leads to an outward shift in the demand for product A, which raises its price and so on. This interaction continues until post-regulatory equilibrium is established at (P_A^R, Q_A^R), (P_B^R, Q_B^R).

Figure D-2. Multiple market effects of VOC regulations.

D.3 COMPUTING CHANGES IN EQUILIBRIUM PRICES AND QUANTITIES

The change in equilibrium prices and quantities for the products affected by the content limits and their substitutes can be numerically computed by adjusting the equations in the multimarket supply and demand system to reflect the imposition of these limits. For each market, i, the equilibrium change in quantity supplied of each product affected by the regulations equals the sum of the supply changes from each of the producer subgroups:

$$\Delta Q_i^S = \Delta Q_i^X + \Delta Q_i^F + \Delta Q_i^R + \Delta Q_i^U. \qquad (D.6)$$

The change (from baseline) in quantity supplied by the withdrawal sector is simply the negative of the quantity originally supplied by that group:

$$\Delta Q_i^X = - Q_i^X. \qquad (D.7)$$

The change in quantity supplied from the fee-paying sector is specified as follows:

$$\Delta Q_i^F = e_i^F (Q_i^F / P_i)(\Delta P_i - F_i) \qquad (D.8)$$

where e_i^F is the supply elasticity of the fee producers in market i, ΔP_i is the change in equilibrium market price, and other terms are as previously defined (without the subscripts). $\Delta P_i - F_i$ is the change in "net price" for the fee-paying producers (i.e., the change in unit process less the unit fee).

The changes in quantity supplied from the reformulating group and unconstrained groups, respectively, are

$$\Delta Q_i^R = e_i^R (Q_i^R / P_i)) \Delta P_i \qquad (D.9)$$

$$)Q_i^U = e_i^U(Q_i^U/P))P_i. \quad (D.10)$$

These producers respond to the increase in price with no counteracting effect on costs. Given the higher price in the post-regulatory equilibrium, output will increase from these two groups of producers.

The aggregate change in equilibrium supply quantity can now be restated by combining the preceding five equations:

$$)Q_i^S = - Q_i^X + e_i^F(Q_i^F/P_i)()P_i-F_i) + e_i^R(Q_i^R/P_i))P_i + e^U{}_i(Q^U{}_i/P)_i)P_i \ . \quad (D.11)$$

The change in market demand for each product is given by

$$)Q_i^D = E_{ii}(Q_i/P_i))P_i + E_{ij}(Q_i/P_j))P_j \quad (D.12)$$

where E_{ii} is the own-price demand elasticity for product, i and E_{ij} is the associated cross-price demand elasticity between products i and j. Consumer demand theory supports the assertion that own-price elasticities are negative and that cross-price elasticities of substitutes are positive. To attain equilibrium, the change in quantity demanded must equal the change in quantity supplied in both markets:

$$)Q_i^D =)Q_i^S. \quad (D.13)$$

This provides a system of M*3 equations in M*3 unknowns, where M equals the number of markets affected by the regulation. This can be reduced to an M*2 equation system, simply by substituting $)Q_i^D =)Q_i^S =)Q_i$. This system can be solved simultaneously to compute the change in equilibrium price and change in equilibrium quantity for each market. To do this, baseline market data, model parameters (supply and

demand elasticities), and an empirical characterization of the various supply shocks alluded to above are needed.

D.4 COMPUTING WELFARE EFFECTS

Changes in the market equilibrium cause changes in resource allocation, which, when quantified, provide measures of how the welfare costs of the regulation are distributed across groups affected by the regulation. The groups focused upon here are architectural coatings producers and consumers, because the changes in prices and quantities directly affect their welfare. Since fee payments are considered, the government sector is also included in the welfare analysis because they collect the fee revenues. This study does not measure the welfare benefits of reductions in VOC emissions, a value against which these costs may be measured to determine the net value to society of the proposed regulatory structure.

D.4.1 Effects on Architectural Coatings Producers

The profits earned at the new equilibrium to the profits earned at the old equilibrium can be compared as a measure of effects of the regulation on the individual producer. Foregone baseline profits (B^0) provide a measure of the loss to producers that choose to exit rather than reformulate:

$$)B = B^{R^*} - B^0 = -B^0. \qquad \text{(D.14)}$$

For the remaining producers, the change in profits is affected by several factors, including the incurrence of the fixed reformulation cost and any associated changes in price, quantity, and marginal cost.

The remaining firms' costs may be affected through either the reformulation cost or the fee payment. The effect of the content limit on producers is generally not uniform and thus raises some distributional considerations. As indicated above, shifts in the aggregate supply function will cause the market price to rise. For some producers, the benefits of the price increase may outweigh the net costs of compliance. This is certainly the case for producers of coatings with VOC content below the regulatory standards, because they incur no reformulation costs but would gain from the rise in market price sparked by the compliance costs and/or product withdrawals incurred by their competitors. Alternatively, fixed reformulation costs may be substantial for some producers, outweighing the positive price effect. The profit effect will be negative for those producers. Other producers may fall in the midrange, where the price benefits and cost effects essentially offset each other.

Changes in producer welfare are generally reported as changes in producer surplus. The aggregate change in producer surplus for the withdrawn-product producers equals the sum of forgone profits from all withdrawn products in market i:

$$)PS_i^X = -\sum_{j=1}^{N_i^X} B_{ij} \ . \qquad \text{(D.15)}$$

The j subscript indicates forgone profits from the j'th product in market i. N_i^X is the number of withdrawn products in market i. The change in producer surplus from the reformulating sector can be approximated as follows:

$$)PS_i^R =)P_i \bullet Q_i^R + 0.5 \bullet)Q_i^R \bullet)P_i - (R_{ac} \bullet N_i^R). \qquad \text{(D.16)}$$

ΔP_i is the change in equilibrium price, ΔQ_i^R is the change in equilibrium quantity from the reformulating producers, Q_i^R is the initial quantity of the reformulating producers, R_{ac} is the annualized reformulation costs, and N_i^R is the number of products needing reformulation.

The change in producer surplus for the fee-paying producers is initially computed as follows:

$$\Delta PS_i^{F1} = (\Delta P_i - F_i) \bullet (Q_i^F + \Delta Q_i^F) - 0.5 \bullet \Delta Q_i^F \bullet (\Delta P_i - F_i). \quad \text{(D.17)}$$

The first term reflects the net revenue effects of the price rise less the fee payment and the second term reflects changes in deadweight loss. To this term we must add the fixed cost (per product) associated with fee recordkeeping requirements so that the full welfare effect is

$$\Delta PS_i^F = \Delta PS_i^{F1} - FF \bullet N_i \quad \text{(D.18)}$$

where FF is the fixed cost per product of fee recordkeeping and N_i equals the number of products subject to the fee in market i.

Finally, the change in producer surplus for unconstrained producers is

$$\Delta PS_i^U = \Delta P_i \bullet Q_i^U + 0.5 \bullet \Delta Q_i^U \bullet \Delta P_i \quad \text{(D.19)}$$

with the Q_i^U reflecting the quantity supplied by these producers. Total (net) producer surplus effects is simply the sum of the terms above:

$$\Delta PS_i = \Delta PS_i^X + \Delta PS_i^R + PS_i^F + \Delta PS_i^U. \quad \text{(D.20)}$$

D.4.2 Effects on Architectural Coatings Consumers

Changes in consumer welfare are measured by the change in consumer surplus, which quantifies losses due to a combination of the higher price and reduced consumption quantity. This change can be approximated as follows:

$$)CS_i = -)P_i \bullet (Q_i +)Q_i) + 0.5 \bullet)P_i \bullet)Q_i. \qquad (D.21)$$

D.4.3 Effects on the Government Sector

The transfer of fees from the fee-paying producers to the recipient of those fees must be considered. For the purposes of the welfare analysis, the government is identified as the "recipient" of the fees.

$$)GS_i = F_i \bullet (Q_i^F +)Q_i^F). \qquad (D.22)$$

Ultimately, the government may choose to redistribute those fees back to affected producers or consumers or back to other members of society via the Treasury; however, for purposes of quantifying these distributional flows, they are assigned as gains to the government sector.

D.4.4 Net Welfare Effects

The net welfare effects are computed by taking the sum of producer, consumer, and government surplus:

$$)WF_i =)PS_i +)CS_i +)GS_i. \qquad (D.23)$$

This calculation nets out any transfers from one group to another within society (e.g., transfers from consumers to producers through higher prices and transfers of fee revenues

from producers to the government) because these transfers do not affect the total sum of resource costs, just how they are distributed within society.)WF_i provides an estimate of the net social costs of the regulation.